Design Considerations for a Thermoelectric Cooler Controller for the NOνA APD Boxes

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Some Requirements & Specifications – *comments needed please!*

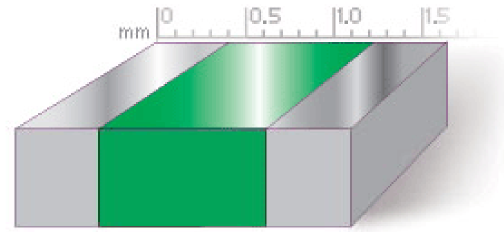
- Minimum cost, low component count, integrated on FEB
- Low noise (specifically, we require that APD signal noise level (<≈ 250 e rms) is not changed more than 1% when TEC controller is enabled or disabled)
- Efficiency (85-90% would be desired, but looks like maybe 80% is more realistic, TBD)
- Fixed ≈ -15 °C setpoint (set by a fixed resistor value or trimpot (not linearized) – there is no remote control)
- TEC drive power: 3 W (at voltage range 1.5 – 6 V, we get to choose this, Brice says)
- Temperature sensor: NTC thermistor, resistance ≈ 10 kΩ at setpoint
- Remote readout that loop is in regulation, or better still, readout the drive level – but no remote temperature readout
- Remote enable/disable (for in-system noise diagnostics)
- Protection of TEC; optional soft-start
- Required temperature stability to ±0.5 °C† over aging, line variation, environmental ±10 °C (?)
- Absolute accuracy of setpoint ±1 °C† – this could get expensive…
- TEC drive current (high-frequency) ripple <10% (or efficiency will be degraded – see http://www.marlow.com/TechnicalInfo/power_supplies.htm)
- Estimated thermal response time constant: (10 K/W)×(0.88 J/g×K)×(1.1 g)†† = 9.7 s

Notes: † From NOVA-doc-147-v4 – based on what considerations???

†† 1.1 g is my wild guess as to the effective thermal mass, $(20\ mm)^2$×(1.5 mm) RO-4003

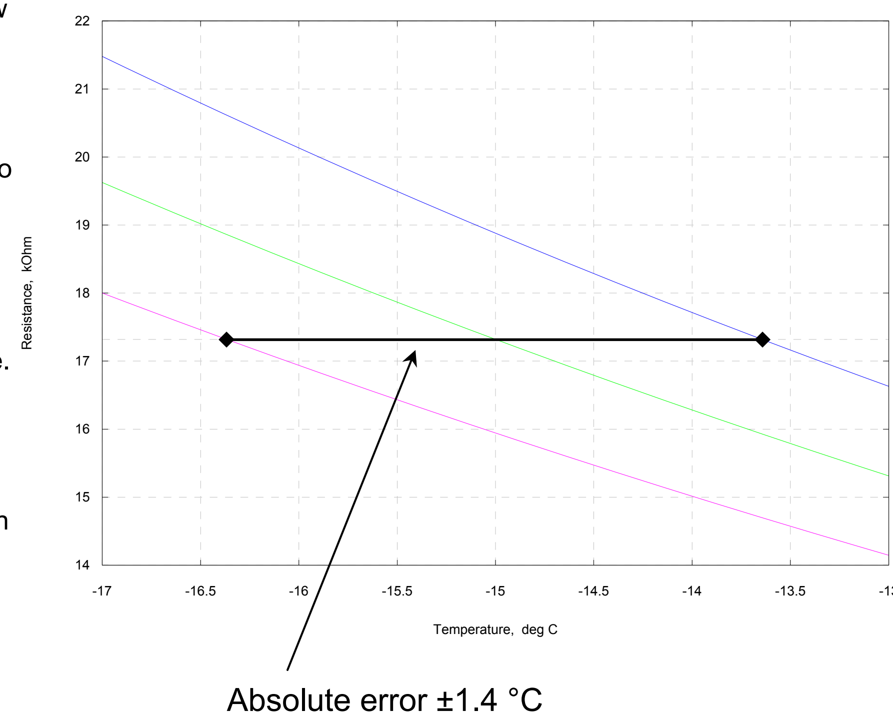
NTC thermistor characteristics

http://www.betatherm.com (excerpted)



Introduction
The 0603 Surface Mount NTC Thermistors from Betatherm are the ideal choice for general temperature sensing and compensation network applications in circuits that require dependable NTC thermistor characteristics.
They are available in a wide variety of standard SMD configurations from the 1206 to the 0402 packages. An extensive range of resistance values and tolerances are offered in all of the standard SMD packages. Standard resistance values from 40 ohms to 500 K ohms are manufactured in the different packages. Details of standard resistance values are given for each of the sizes (1206, 0805, 0603, and 0402) as per detailed in the table below.
With resistance tolerances of ±1%, ±3% and ±5%, these NTC devices are suitable for the most demanding requirements. The operating temperature range for these devices is from -40ºC to +125ºC. They are suitable for both flow and reflow soldering processes.

SMD32KF410H resistance vs. temperature
and error band (incl. 1% reference contribution)



Comparison between NTC thermistors and Metal Element RTD's
Sensitivity: A thermistor offers the best sensitivity of any temperature sensor type in the range from -50°C to + 250°C. This sensitivity is of the order of -4% to -6% per °C. In contrast, Metal Element RTD's have a sensitivity of approximately 0.4 %/°C. In absolute terms the sensitivity of an NTC thermistor can range from several ohms to several hundred ohms per °C, while the sensitivity of a metal element RTD is of the order of 0.4 ohm to 4 ohm per °C.

Size: Both an NTC thermistor and Metal RTD can be made to a very small size. In terms of mechanical and electrical performance, NTC thermistors remain durable and robust at small sizes whereas Metal RTD's are more fragile.

Signal Conditioning: The combination of high basic resistance values and high sensitivity of NTC thermistors allows for easy interfacing to instrumentation without significant signal conditioning. Metal element RTD's typically require signal conditioning and amplification and are more susceptible to electrical noise effects.

Temperature Range: The operating temperature range for NTC thermistors is from -100°C to + 300°C. Metal RTD's offer a wide temperature range from -260°C to+850°C.

The Basic Options

- Linear regulator

  ▼Restricted control range: thermal loads, TEC's, cable drops must match to ±8% for 85% efficiency, and power supply must be carefully adjusted and monitored

  ▲Very simple circuit, really zero EMI

- Trapezoidal on-off control (based on temperature)

  ▼**!!** Thermal cycling may contribute to TEC failure

  ▼Temperature stability is (probably) worse than any circuit which attempts to hold temperature constant, certainly in the short term

  ▲Very simple circuit

- Trapezoidal low-frequency, i.e., ≈ 500 Hz, PWM/PFM/etc. (unfiltered)

  ▲Efficient (perhaps 90 – 95% electrical efficiency)

  ▼TEC efficiency may be lowered (but how much?) compared with DC operation

  ▼Possible EMI issues (solvable at the expense of efficiency and/or parts count by slowing down the transitions)

  ▼Suitable PWM controller not available as simple IC, will require more parts to implement – ▲*unless, perhaps, we can make good use of "extra" resources in the FEB FPGA*

  ▼Poor line rejection, although this can be mitigated with a slightly more complex PWM controller

The Basic Options - continued

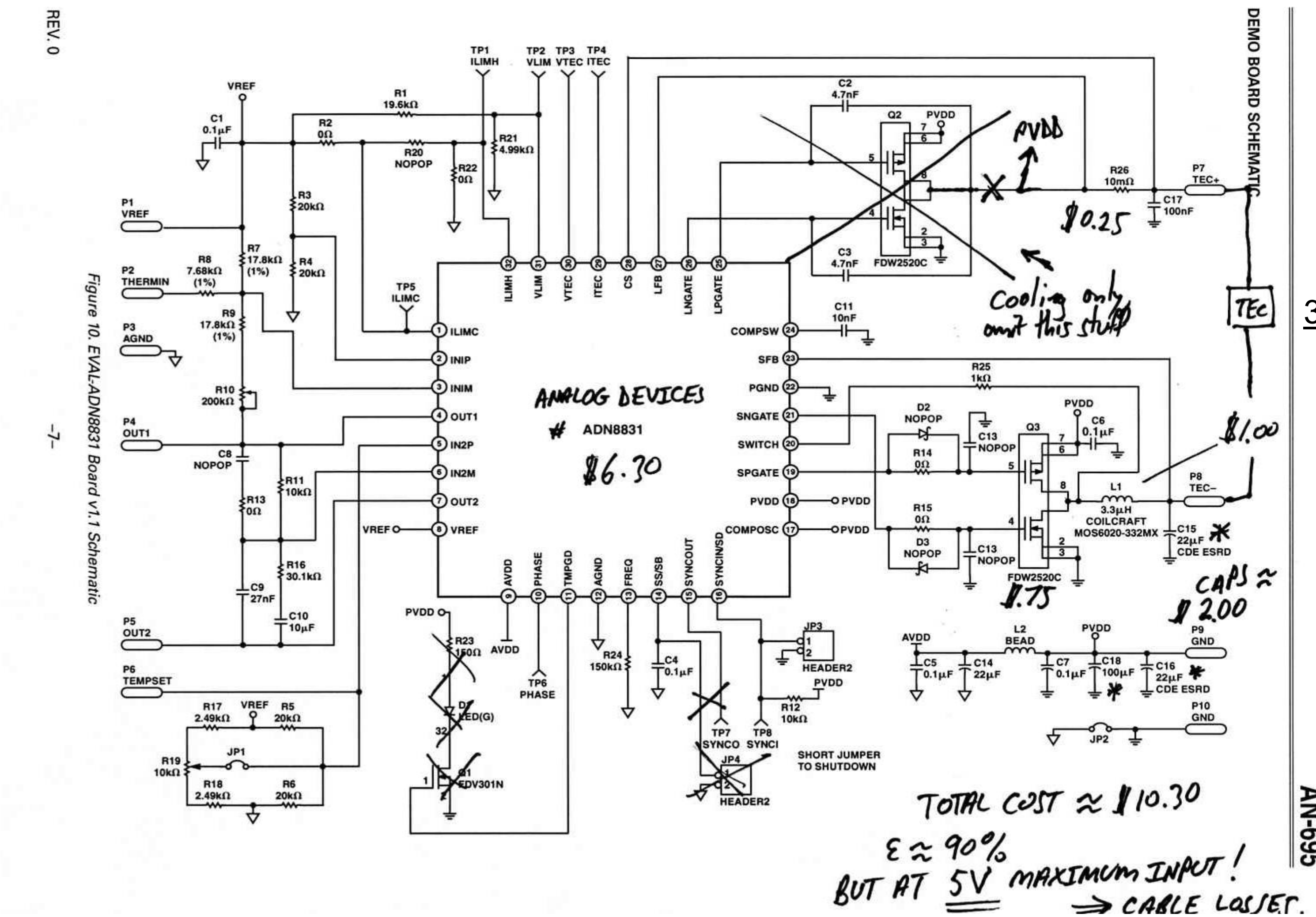
- Switching converters with current-mode control
  - ▲All of these maintain essentially DC current in the TEC, like the linear regulator does
  - ▲All have excellent line regulation – power supply ripple or poor regulation is ok
  - ▲All allow for somewhat higher power supply voltage to reduce cable losses
  - Integrated TEC controller chips
    - ▼Many features, bidirectional, high power, external power switches → higher cost
    - ▼Basically all are buck converters, see below
    - ▲Thermistor amplifier and loop compensation built-in (for <u>all</u> the other options at least a dual op-amp is required, ≈ \$1.50)
  - Buck converter
    - ▼Potentially bad EMI due to high current pulses on line (input) side, filters may be applied of course, but it still seems risky…
    - ▲Wide selection of low-cost, high efficiency integrated switchers
    - ▲“Synchronous” buck converters can maintain efficiency even for low TEC voltages
  - Ćuk converter
    - ▲Essentially DC input current, worries about EMI are reduced
    - ▲Wide selection of low-cost, high efficiency integrated switchers
    - ▼Switch losses are ≈ 2× that of buck converter

Survey of Available Integrated TEC controller chips

Mfr	P/N	Cost @ 1k	Size, mm	Pins	Switches	Freq, kHz	Control Amps	Remarks
AD	ADN8831	6.31	5x5	32	external†	200-1000	internal	
Maxim	MAX1968	7.5	10x6.5	28	internal, 3A	500, 1000	external	
Maxim	MAX1978	10	7x7	48	internal, 3A	500, 1000	internal	= MAX1968 + integrated op-amps
Maxim	MAX8521	6	5x5	20	internal, 1.5A	500, 1000	external	
LT	LTC1921	18.17	5x5	32	external†	200-1000	internal	nicest part probably, but see the price!
Analog Technologies	TEC-A1LD	62	25x26	16	internal	unspecified	internal	filter internal (hybrid not monolithic IC)
Hytec	HY5605	*(certainly not cheap)*	18x23	10	(linear, internal)	-	internal	linear controller, low efficiency

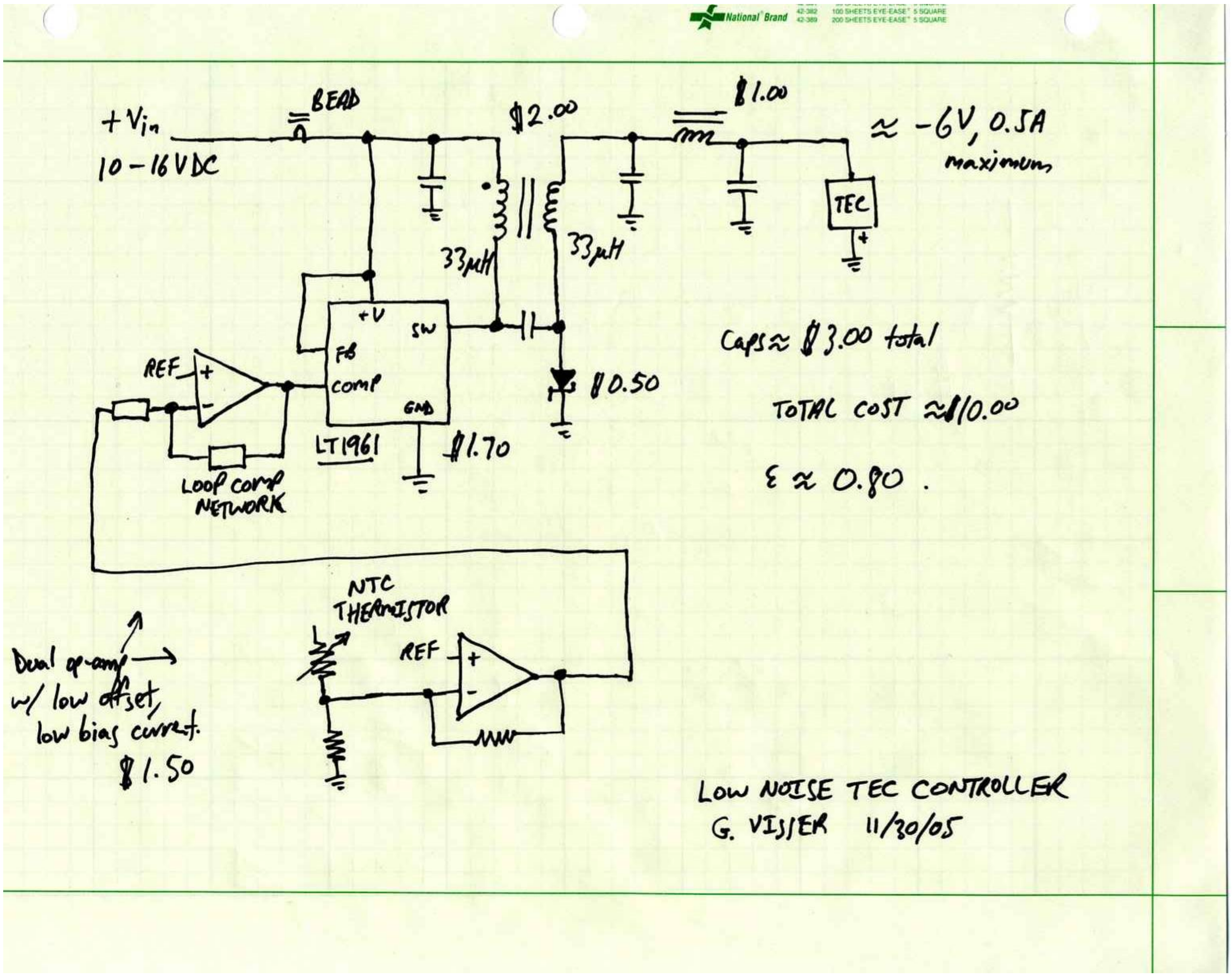
† Note: Add about $0.75 for external switch FET's.

Synchronous buck converter TEC controller based on ADN8831



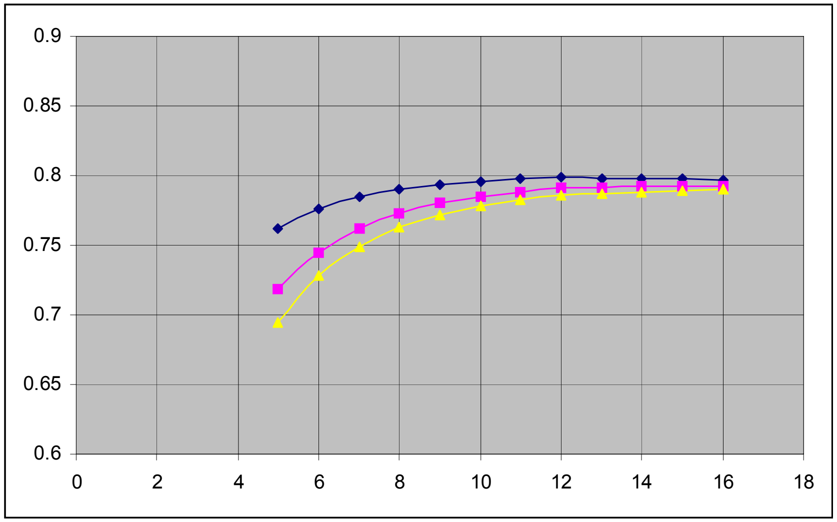
3V, 1A

Ćuk converter TEC controller based on LT1961



Ćuk converter TEC controller based on LT1961

Efficiency vs. supply voltage @ 3 W, 6 V output to TEC,
with no cable losses, and with 50 feet @ 16AWG and 18AWG



Efficiency vs. TEC voltage @ 3 W, with 50 feet @ 18AWG